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VESUB TECHNOLOGY DEMONSTRATION: PROJECT SUMMARY

APRIL 1999

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13. ABSTRACT (*Maximum 200 words*)

The objective of this report is to provide a chronology of project events and an assemblage of critical technical and process issues that played a significant role in the development of the Virtual Environment for Submarine Shiphandling and Piloting Training (VESUB) system, and which offer an insight into project development for this and other training systems that employ state-of-the-art technologies. This is the third in a series of reports to document the VESUB project. This report will be used in conjunction with the previous publications in the series, NAWCTSD TECHNICAL REPORT 97-013 and 98-003, which documented the usability analysis for the VESUB Instructor/Operator Station and the VESUB TEE, respectively. Finally, six conclusions and recommendations are provided to support future improvements in VE training system development: 1) VESUB provides effective shiphandling training; 2) Team communications is a must in the development of complex systems; 3) Legacy based system development must be closely evaluated; 4) Configuration Management is essential for success; 5) Complex scenes require sufficient fidelity to support training requirements; and 6) VE offers unique presentation capabilities that should be exploited.

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EXECUTIVE SUMMARY

PROBLEM

In recent years, Virtual Reality (VR), often called Virtual Environments (VE), has received considerable attention among training developers. This is due in part to media hyperbole over applications of VR in the entertainment industry, but even more so because training developers recognize the potential of VR as a flexible and effective training medium. Demonstrations and evaluations of VR training systems can help define the appropriate use of VR technologies to achieve their potential.

Coming to grips with the elements related to the production of any training system requires the development team to conceptualize, plan, and effectively execute activities that will result in a fully functional trainer. Add to the already complex nature of this task the employment of a leading edge technology, such as VR, and you substantially increase the risk and difficulty of the process.

OBJECTIVE

The objective of the Virtual Environment for Submarine Shiphandling and Piloting Training (VESUB) project was threefold: (1) to develop, demonstrate, and evaluate the training potential of a stand-alone virtual reality-based system for Officer of the Deck (OOD) training; (2) to determine if this system could be integrated with existing Submarine Piloting and Navigation (SPAN) training simulators; and (3) to determine the viability of virtual reality technology as a training tool. This report looks at the overall project from a chronological perspective, the teaming strategy planned and implemented in the accomplishment of the VESUB effort, and the programmatic and technical lessons learned over the course of the project.

APPROACH

VESUB was developed by an integrated team of government and industry members who were able to simultaneously address the technical issues related to building a VR training system, the task related elements of submarine shiphandling, and the usability and training effectiveness of the system. The goal of the VESUB project team was to assemble and harness the knowledge and skills necessary to: (1) fully understand the piloting and navigation task that was to be trained; (2) support the modeling and programming necessary to create and operate within the virtual environment; and (3) design and implement an effective instructional design that would ensure task related knowledge transfer.

The VESUB research team included research psychologists, visual engineers, computer engineers, and submarine subject matter experts. Nichols Advanced Marine Enterprises (AME) integrated the software and hardware elements for VESUB. To save time and money, VESUB was developed by leveraging AME's Virtual Ship application, a commercial product that has

been used for several years to train surface shiphandling tasks in a rear projection theater environment.

Subject matter experts (SMEs) were drawn initially from fleet training and operational commands. However, to meet the demands of daily development, Sonalysts, Inc. was placed under contract by NAWCTSD to provide SME support focused on submarine piloting and navigation, as well as general submarine operations.

The VESUB technology demonstration system used a high-resolution, head mounted display (HMD) to provide the trainee with a simulated 360 degree, 3D visual representation containing many of the required cues associated with harbor and channel navigation, as well as accurate cultural features and varying environmental conditions. A speaker-independent voice recognition and speech synthesis system was used as the primary interface for communications between the trainee and the computer generated autonomous agents (simulated ship's personnel) to control the system. This provided a communications-training element for this complex task. Visual scene rendering, computation of harbor currents and wind effects, and operation of own ship and other traffic ships required state-of-the-art computer systems and software applications.

RESULTS

As the VESUB effort matured, it became increasingly clear that effective development team interactions would contribute significantly to the success of the project. Team management and communications, along with technology related issues, required the development of various conferencing and other communication methods to control development and system verification at the two primary work sites of NAWCTSD and AME. These methods did not always result in a thorough understanding of issues by all team members.

The VESUB project culminated in a two-phased Training Effectiveness Evaluation (TEE) conducted at Submarine Training Facilities. The TEE used Navy personnel as subjects and was documented in NAWCTSD Technical Report 98-003. The results of the TEE demonstrated that the VESUB technologies provided effective training on shiphandling skills for novice and expert alike. The generalizable nature of the findings also supports the potential for VR as a training delivery modality.

Through the course of the VESUB effort, several important lessons were learned by the project team. Some were technical, and others related to the nature of the development of a system through the team process. Details on these lessons are presented in this report, along with the project chronology and a technical review of the project.

CONCLUSIONS AND RECOMMENDATIONS

The VESUB TEE clearly demonstrated that a VR training delivery system could provide effective training. However, there are still several areas where additional research and development is needed. Among these are the refinement of the voice recognition and synthesis

system, development of artificial intelligence to be used (in conjunction with the voice recognition and synthesis processes) to support communications logic, and the development of the specialized virtual crew concept to automate and improve system performance. Additionally, visual scene improvements that will better demonstrate real-world environmental issues (such as currents, eddies, earth's curvature, and image contrast) and improvements to VESUB's software integration process are necessary.

The following conclusions and recommendations are discussed:

- VESUB provides effective shiphandling training
- Team communications is a must in the development of complex systems
- Legacy based system development must be closely evaluated
- Configuration management is essential for success
- Complex scenes require sufficient fidelity to support training requirements
- VE offers unique presentation capabilities that should be exploited

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PROBLEM

In recent years, Virtual Reality (VR), often called Virtual Environments (VE), has received considerable attention among training developers. This is due in part to media hyperbole over applications of VR in the entertainment industry, but even more so, because training developers recognize the potential of VR as a flexible and effective training medium. Coming to grips with the elements related to the production of any training system requires the development team to conceptualize, plan, and effectively execute activities that will result in a fully functional trainer. When a new technology, such as VR, is added to an already complex task, the risk and difficulty of the process is substantially increased. To successfully meet the demands of the project, the Virtual Environment for Submarine Shiphandling and Piloting (VESUB) team was assembled to harness the knowledge and skills necessary to: (1) fully understand the shiphandling task that was to be trained; (2) support the modeling and programming necessary to create and operate within the virtual environment; and (3) design and implement an effective instructional design that would ensure task related knowledge transfer.

OBJECTIVE

This is the third in a series of reports to document the VESUB project. This report supplements the previous publications in the series, NAWCTSD Technical Reports 97-013 and 98-003, which documented the usability analysis for the VESUB Instructor/Operator Station and the VESUB TEE, respectively. The objective of this report is to provide a chronology of project events and an assemblage of critical technical and process issues that played a significant role in the development of the VESUB system, and which offer an insight into project development for this and other training systems that employ state-of-the-art technologies.

ORGANIZATION OF THE REPORT

The Background section provides: 1) a brief description of the submarine shiphandling task and the training requirement for the VESUB training system; 2) an explanation of why submarine shiphandling was chosen as the technology demonstration task; and 3) a chronology of the VESUB project, which includes an overview of the planned and executed stages. The Simulation and Training Issues Section describes both programmatic and technical issues identified in the VESUB project. In describing these issues it is hoped that the lessons may be applied to other projects. The importance of team communications to project performance, especially when members are not co-located, and the impact of good and poor communications are discussed. The use of subject matter experts (SMEs), both internal and external to the Government, is reviewed and evaluated. Finally, Conclusions and Recommendations are provided to help in the development of the operational VESUB training system (VESUB 2000) and other VR-based training systems.

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THE VIRTUAL ENVIRONMENT FOR SUBMARINE SHIPHANDLING AND PILOTING (VESUB) TRAINING TECHNOLOGY DEMONSTRATION PROJECT

BACKGROUND

The objective of the VESUB project was threefold: (1) to develop, demonstrate, and evaluate the training potential of a stand-alone VR-based system for submarine shiphandling training; (2) to determine if this system could be integrated with existing Submarine Piloting and Navigation (SPAN) training simulators; and (3) to determine the viability of VR technology as a training tool. VESUB proceeded as a multiphased program, consisting of: (1) requirements determination; (2) formative evaluations; (3) training effectiveness evaluation (TEE); and (4) transition of R&D results to support the acquisition of operational systems (VESUB 2000).

The Submarine Officer of the Deck (OOD) mans the bridge with the assistance of a lookout and, many times, a Junior Officer of the Deck (JOOD). His responsibilities include all aspects of ship's evolutions, and the safe navigation and piloting of the ship. In his shiphandling tasks, he must demonstrate an understanding of: the environment; limitations of channels and harbors; available navigational aids; contact management; and rules of the nautical road.

The placement of the OOD, literally on the top of the submarine, with a 360-degree view of his surroundings, provided an excellent setting for a VE. In addition to this visual plane, the Submarine OOD manages a complex task in the execution of his responsibilities. Though isolated on the ship's bridge, he monitors and observes the environment, and directs the actions necessary to CONN (maneuver) the submarine through harbor and channel. He communicates his desires through voice commands over electronic circuits and receives both voice and visual confirmations of his orders. Because of the important visual component of the task and the Navy's need for a simulation capability, the surfaced submarine shiphandling task was determined to be a prime candidate for examination of the effectiveness of VR systems for training applications.

VESUB CHRONOLOGY

Project Initiation

In May of 1994, a Problem Description and Needs Justification (PDNJ) was submitted to the Manpower, Personnel, and Training (MPT) 6.3 Research and Development Program by the Naval Air Warfare Center Training Systems Division (NAWCTSD), entitled "Virtual Environment for Submarine Piloting Training." In July of 1994, a Technical Development Plan was requested on this topic from the Advisor for Research Management at the Bureau of Naval Personnel. The Virtual Environment for Submarine Shiphandling and Piloting Training (VESUB) project began in October of 1994.

Contractual Support

In June of 1995 a contract was established with BBN Systems and Technologies to assist in the determination of VESUB requirements. This task was accomplished through questionnaires and interviews with fleet SMEs and by using a feasibility demonstration system developed under the Office of Naval Research-funded 6.2 Virtual Environment Training Technology (VETT) project. This system was used as a knowledge elicitation tool to obtain detailed requirements inputs from the SMEs. Although it only included a simplified harbor scene and submarine model, which was viewed through a low resolution HMD, this system afforded the SMEs a chance to experience a virtual environment. VESUB requirements were documented in a NAWCTSD Special Report (Tenney, Briscoe, Pew, Bradley, Seamon, & Hays, 1996).

In March of 1996 contracts were established with Nichols Advanced Marine Engineering (AME) and Sonalysts, Inc. The software and hardware integration for VESUB was executed by AME. To save time and money, VESUB was developed by leveraging AME's Virtual Ship application, a commercial product that has been used for several years to train surface shiphandling tasks in a rear projection theater environment. SMEs were drawn initially from fleet training and operational commands, however, to meet the demands of daily development, Sonalysts was placed under contract by NAWCTSD to provide SME support focused on submarine piloting and navigation. This included the accomplishment of periodic system reviews to evaluate system improvements and software deliveries from the developer. Sonalysts also collaborated in identification of the critical learning elements that would be used to measure trainee performance and in conducting the TEE.

Perceptual and Cognitive Task Analysis

A perceptual and cognitive task analysis was conducted using "Seaman's Eye" as a means to focus the effort. "Seaman's Eye" is a term used by experienced ship handlers to describe the collective skills required by the OOD during surface evolutions. Through interactions with expert consultants, like submarine commanding officers and harbor pilots, the team derived the following definition of "Seaman's Eye" to guide the perceptual and cognitive analysis.

The total situation awareness of the shiphandling environment and the ability to safely maneuver the vessel in all conditions.

Iterative probing of SMEs, using focused group discussions at Navy training facilities and in the NAWCTSD laboratory, detailed eight perceptual and twelve cognitive components that make up this complex concept (see Table 1). These components were used to make hardware, software, and instructional decisions during the formative evaluation and later phases of the project (Hays, Vincenzi, Seamon, and Bradley, 1998).

Table 1
Components of "Seaman's Eye"

PERCEPTUAL COMPONENTS
1P. Locating and Identifying Navigation Aids
2P. Judging Distance
3P. Identifying the Start and Completion of Turns
4P. Locating, Identifying, and Avoiding Obstacles
5P. Sense of Ship's Responsiveness
6P. Recognizing Environmental Conditions
7P. Recognizing Equipment Failures
8P. Detecting and Filtering Communications
COGNITIVE COMPONENTS
1C. Understanding the Relationship of Visual Cues to their Representations on Charts
2C. Understanding Relative Size and Height/Range Relationships, and Angle on the Bow (AOB)
3C. Understanding Advance and Transfer
4C. Understanding the Effects of Tides, Currents, Wind, and Seas
5C. Understanding Rules of the Road
6C. Understanding Relative Motion (Direction and Speed)
7C. Understanding Methods to Differentiate and Prioritize Traffic Contacts
8C. Understanding Ship's Operation Under Harbor Directives
9C. Understanding Methods to Deal with Uncooperative Traffic
10C. Understanding Correct Operation of Ship's Systems
11C. Understanding When and How to Take Corrective Actions
12C. Understanding Effective Communication Procedures

Formative Evaluations

The formative evaluation phase was conducted in the laboratory at NAWCTSD. Whenever AME delivered an improved iteration of the VESUB software, it was evaluated against the functional requirements by the VESUB research team. Data for the formative evaluations were also collected from eleven fleet and school SMEs and nine Navy reservists with shiphandling experience following extensive exposure to VESUB. As soon as the formative data were collected, the results were provided to AME to guide system improvements. The formative evaluations focused on both the functionality of the trainee interface (e.g., the fidelity of objects in the visual scene, the functionality of the voice recognition system, and the hydrodynamics of the ship models) and the usability of the Instructor/Operator Station (IOS).

Training Effectiveness Evaluation (TEE)

TEE Approach. The TEE for the VESUB technology demonstration system was conducted at the Submarine Training Facility in Norfolk, Virginia and the Naval Submarine School in Groton, Connecticut during the winter and spring of 1998. The TEE used Navy trainees with various levels of shiphandling experience (novice to expert) to determine the effectiveness of the VESUB system and to help determine how the technology can be integrated into Navy training. At each site, the VESUB system was set up in a room where the TEE could be conducted without interfering with ongoing training.

Forty-one participants experienced three VESUB scenarios. The first, was an orientation scenario to allow them to experience and practice system functionality, the second, was a training scenario which targeted several specific shiphandling tasks (derived from the perceptual and cognitive task analysis), and the third, was a comparable scenario to test the trainees' improvement on these shiphandling skills. Prior to the first scenario, demographic data were collected and a comfort questionnaire was administered to assess the participants' physical condition. After completion of each scenario, the comfort questionnaire was again administered to assess any physical changes experienced by the participants. Finally, each participant provided comments on the VESUB system and recommendations for its use and improvement.

TEE Results. Data were collected on fifteen shiphandling variables grouped into seven skill categories. A mixed factorial analysis of variance (ANOVA) design, with experience as the between-subjects variable and scenario session (training and testing) as the within subjects variable, found significant learning (skill improvements) for all experience levels (0 to 14 years) on eleven of the fifteen variables. For example, trainees improved:

- 39% in checking range markers
- 33% in visually checking the rudder
- 13% in issuing correct turning commands
- 57% in contact management skills
- 44% in reaction time during a man overboard (MOB) event
- 29% in using correct commands during the MOB event
- 40% in using correct commands during a yellow sounding event

No major simulator side effects problems were found. Less than 5% of the trainees experienced side effects that were detrimental to training, even though trainees averaged almost two hours in the head-mounted display (HMD). Details on these and other TEE data are presented in Hays, et al. (1998).

SIMULATION AND TRAINING ISSUES

Over the course of the VESUB project, team members learned a variety of lessons about the problems of developing a complex state-of-the-art VE training system. Though resources often limited project response to these lessons, their importance to VESUB and its follow-on training system, as well as other training systems that employ similar processes, could prove to be significant.

These lessons included a wide range of issues, from hardware and software configuration management and legacy system interfacing, to speech and visual system integration. Other key areas included task-specific detailing for accuracy and training effectiveness, as well as, project management and control issues that are not often considered during project planning. Discussing these lessons as they relate to the VESUB functionality requirements established by the team should provide a better level of understanding of the nature and difficulty faced by developers in the VE arena.

SYSTEM HARDWARE AND SOFTWARE IMPLEMENTATION

Computer Platforms

The VESUB technology demonstration system consisted of a Silicon Graphics (SGI) Onyx Infinite Reality (IR) and two desktop SGI Indy computers. The SGI Onyx was selected as the image generator for this project because it was the only system available with full hardware anti-aliasing and the ability to rapidly construct polygons for the visual scene at the high refresh rate required to meet the VESUB task requirements.

Figure 1. VESUB Operators Running the System in the NAWCTSD Lab

Figure 1 shows the VESUB system in the NAWCTSD laboratory during the formative evaluations. Two instructors are seated at the IOS while a trainee, wearing the HMD, issues voice commands. The two SGI Indy computers were employed as the IOS and to support applications that were not compatible with the operating system software running on the Onyx. The voice recognition software ran on one unit while the environmental sound software ran on the other. This layering of software may not have been optimum. However, it was considered acceptable for use in a technology demonstration. Hosting all processes on a single platform would have reduced interface issues and configuration concerns had all the software been compatible.

Visual System

The HMD initially used for the feasibility demonstration system and the initial stage of the VESUB project was a Virtual Research VR4. This HMD, which used a liquid crystal display with relatively low resolution, did not sufficiently support the detailed rendering of the modeled environment for the shiphandling task. Specifically, the ability to see objects at distances, effective contrast and shading, and the ability to read details on displays and charts required a higher resolution display.

An n-Vision high resolution Datavisor HMD was acquired to improve the usability of VESUB tools and resulted in significant improvements in trainee performance. Additional improvements are still required to effectively display many of the visual cues associated with the VE, including the ability to accurately discern currents, tide rips, details of lights and shapes (e.g., types, colors, shapes) and an enhanced field of view in both horizontal and vertical planes. Key improvements to HMD usability would result from improved weight, comfort, field of view, balance, and reduction in ambient light from external sources.

Software

The primary software used in the VESUB system is a modified version of Virtual Ship, a commercial product licensed from AME. One of the functions of Virtual Ship was to integrate and work with the several layers of software that provide the functionality required by VESUB. This software is the engine that provides interface and functionality for AME's established shiphandling trainers for commercial and military surface vessels. A complete list of VESUB software is provided in Appendix A. The modified version of Virtual Ship employed in VESUB had to simultaneously operate with several revisions of the SGI IRIX operating system. This was due to incompatibilities experienced between required utility applications necessary for VESUB's operation. These incompatibilities were the primary reason that all processes were not loaded and running on the Onyx computer.

The complexity of the Virtual Ship processes caused occasional problems, as did the use of "patches" within the operating system. These faults generally manifested themselves as files not being readily found or the incorrect application of tools, which resulted in system lock-up or faulty operations. Operational systems may be better served with a system that operates more

seamlessly and which is less layered in design. For the most part, however, the Virtual Ship structure provided the necessary functionality for the VESUB technology demonstration.

The proprietary nature of the Virtual Ship program further complicated the VESUB process as programmers at NAWCTSD were unable to access source code to make changes that would improve the system, even after the contracted period of performance. An off-the-shelf application or an open system architecture would afford the Navy better control of modifications such as the addition of new ship models or enhanced functionality.

PROGRAMMATIC ISSUES

Project Management Process

The VESUB project was planned and executed by a team whose members were located at different geographic sites. This proved to be a critical issue in the performance of the VESUB system. The project team had to simultaneously address the technical issues related to developing a VR training system (e.g., identifying system requirements to support acceptable refresh rates) and accuracy of the task related elements of submarine shiphandling (e.g., accurate characteristics of ship performance). AME, Sonalysts, and NAWCTSD team members communicated with each other via e-mail and telephone, as well as, face-to-face interactions in the lab. Engineers at AME and NAWCTSD established methods for transferring software revisions and for working together to load and execute programs. Additionally, the team conducted a biweekly telephone conference to ensure an open communications environment.

This communications cycle was accompanied by an action list that established and tracked issues. The list and its content were simple, and actions were distributed to appropriate team members. Subsequently, the action list was updated through meetings and telephone conferences. Prioritization was also an issue. The government established priority for most of the action items, but they were not always the focus of the developers. Deadlines shifted, milestones passed, and deliveries were delayed. Sometimes this was because related work had to be accomplished as a block. However, too often scheduling was accomplished without apparent regard to the established priority. A more formal action/task tracking procedure is essential for such complex efforts as VESUB.

The goal of the formative evaluations was to allow SMEs to use and evaluate the VESUB system in the NAWCTSD lab and to provide direct feedback to the development team, who would in-turn modify the system based on this expert commentary. In general, this process worked well. However, developers not knowing when to ask questions of the SMEs, would move ahead with their programming believing that they were on the right development track. Later they discovered their programs were incorrect and needed to be changed. These modifications caused delays, wasted resources, and created internal team conflicts that degraded the development process.

Configuration Management

The desired functionality of the VESUB training system called for upgrades in all areas of technology. The VE technology demonstration required AME and NAWCTSD to set up duplicate systems with what was planned to be identical hardware and software suites. NAWCTSD elected to use the SGI hardware from previous research efforts as the foundation computer for VESUB. This required the team to schedule several revisions and upgrades that would bring this machine up to the demands of the project.

The second SGI computer (SGI Onyx 2) was purchased for use at AME's site. This contracted purchase yielded the exact configuration requested by the technical demands of the project. The dual path taken here to secure the hardware proved to be the source of configuration problems that lasted throughout the project's life. The configuration management issues for the hardware hinged around the real differences between upgraded computers and new platforms that were manufactured to the higher standard from the frame up. The laboratory hardware was not effectively upgraded to duplicate the capabilities of the newer model, which led to difficulties in the government's ability to evaluate software features. This configuration mismatch resulted in the two systems performing differently when running identical software revisions.

System developers and modeling/graphics specialists at AME operated from several workstations and were linked to the Onyx through a network. This offered valuable development advantages, but also allowed these team members to simultaneously host other projects on the Onyx. The use of a network structure, as well as the sharing of the platform with other projects, changed the operating characteristics of the system and resulted in variations of software performance between this system and the non-networked Onyx at NAWCTSD. The system was not tested in stand-alone mode before it was shipped to the TEE sites. The lack of stand alone operation and testing resulted in significant operational inconsistencies which were discovered during the first TEE (not enough memory). In fact, system configuration and controls were at fault and corrective actions had to be identified and accomplished at the TEE site. A better process of software quality control and configuration monitoring to ensure that all elements and modules developed will run equally well on all associated training system platforms.

Software management issues resulted from the complex integration called for by the Virtual Ship process. There were incompatibilities that had to be addressed and which drove design considerations for the project. For example, HARK the voice recognition software, was a carryover from the feasibility demonstration system. The developer did not evaluate other systems or weigh the impact of this selection in the broader context of VESUB's operability. HARK's developers had elected to suspend its development for SGI platforms which meant that it would only work on earlier IRIX operating systems. The decision to use Hark forced the design to include an additional SGI Indy station to accommodate this application.

Software licenses also needed to be managed. On occasion, erroneous license expirations caused the system to lock out. Project managers need to secure open ended licenses for all software applications that will be incorporated into their system, and software management needs to be initiated early-on to eliminate this problem.

In Process Reviews (IPR) and Other Meetings

Any complex project requires close liaison between all team-members. For VESUB, it was hoped that communications could be informal wherever possible. It was felt that project resources could best be used on development and integration, rather than on costly travel for team meetings. This approach assumed, however, that the use of telephone conferences and action lists would result in effective team performance. These tools proved to be less effective than anticipated.

One example of a problem that might have been corrected in a face-to-face meeting involved the focus of project development. The VESUB system was based on an existing AME product and the developers were locked into this system and its capabilities. This tended to influence the development path selected, its design, and even its appearance on screen. While AME's project leader committed to addressing submarine related aspects by making required changes to the Virtual Ship product, changes were slow in coming and many were never accomplished.

Potentially, more face-to-face IPRs and other meetings could focus team attention on the objectives and status of the project and allow each team member to be heard. Furthermore, they offer the Principal Investigator a method to formally establish the development path that would optimize resources for overall project success.

Impact of Demos on Development

The objective of the VESUB project was to develop an effective, user-friendly training demonstration that could support a real fleet need and transition into a valuable training system for the Navy. Development time was often at a premium, especially as the process matured towards the scheduled TEEs. VESUB, however, rapidly became one of the most popular systems to show on tours of NAWCTSD. Its use of advanced technologies and the attractive nature of the VR approach made it the preferred demonstration tool to highlight NAWCTSD's skills and capabilities. VESUB's celebrity status had a decidedly negative impact on the ability of the team to focus and accomplish project goals. VESUB researchers often conducted daily demonstrations, some requiring several hours of preparation and execution, which had a real impact on time and resource management for the project.

Shared System Resources

VESUB was one of the most detailed and complex training systems yet undertaken at NAWCTSD. It required several levels of software applications, user interfaces using two I/O paths, detailed modeling and scene rendering, and complex database management. The complexity of VESUB was clear, yet for more than a year other systems were co-hosted on the laboratory Onyx. This detrimentally affected schedules and operations. Team members had to timeshare with these other projects, and demonstrations of unrelated work often required the VESUB team to reschedule their efforts. There were also indications that this co-hosting impacted system operations by slowing processing during VESUB evolutions. Because

processing and refresh rate are considered key elements to the visual performance in the VE presentation, the impact on slower performance was troubling until other project software was removed.

Legacy Software Use in New System Development

VESUB was based on legacy software. This baseline system, Virtual Ship, provided a starting point for the VESUB technology demonstration that included some, but not all, of the functionality called for to meet the submarine shiphandling task. While the positive aspects of leveraging this application may outweigh the negative ones, it is important to note that several deficiencies resulted from this approach. An existing technology tool-set was employed that had not evolved over time. With the explosive growth of technology, this may have artificially constrained VESUB development. Additionally, if the developer is the originator of the legacy system, they may have a predetermined mindset as to how the system should be designed. Existing models, interface methods, development and scenario generation tools are already in place and the easiest path for fielding the follow-on project is through the use of these tools. New approaches may be challenged and, because of this, opportunity for improvement or enhancement may be lost.

Other issues related to streamlining, improved modeling, image generation, interface design, and application management offer other arguments against using legacy systems. This conflict will continue, however, because the employment of these systems often reduces costs, saves time, and offers a list of developmental efficiencies as well. Usability, functionality, applicability and openness of design, as well as projected longevity, should all be considered when evaluating the use of a legacy system as a baseline for an emerging project.

VESUB REQUIRED FUNCTIONALITY

The VESUB technology demonstration system broke new ground in the field of VE training systems development. Several technologies were incorporated to provide the functionality necessary to support the project goals. A wide variety of lessons were learned during this project which will help to support the development of VE training systems. VESUB required functionality was initially identified in Tenney, et al. (1996). These requirements were later detailed by the VESUB team and incorporated into project planning. Table 2 is a status list of these and other requirements. The following discussion provides details on the status of these requirements.

Table 2

Status of VESUB Required Functionality

Requirement	Completed	Partially Completed	Not Completed
SPAN Interface	----------	----------	X
Simulation Requirements			
Submarine Dynamics (688I & 726):			
• Pitch, Roll, & Heave	----------	X	
• Advance & Transfer	----------	X	
• Acceleration/Deceleration	----------	X	
• Turns per Knot	----------	----------	X
• Collision Detection	----------	----------	X
Currents:			
• Effects on Own Ship	----------	X	
• Effects on Contacts	----------	----------	X
• Effects on Buoys	----------	----------	X
• Appearance	----------	----------	X
• Dynamic (Time/Date)	----------	----------	X
Wind:			
• Effects on Own Ship	----------	X	
• Effects on Contacts	----------	----------	X
• Effects on Buoys	----------	----------	X
• Appearance	----------	----------	
Visual Display Requirements			
Own Ship:			
• 360 degree View	X		
• Binocular View	X		
• Topside Areas:			
- Bow	----------	X	
- Bow Wave	----------	X	
- Sail	X		
- Navigation/Anchor Lights	----------	X	
- Periscopes & Masts	----------	X	
- Rudder	X		
- Stern Wake	----------	X	
• Bridge Area:			
- Bridge Suitcase		X	
- Windscreen	X		
- Compass	----------	X	
- Chart Book (dynamic/digital)	----------	X	
- Course Card	X		
- Maneuvering board	----------	----------	X
- Other Bridge Equipment	----------	----------	X
Contacts:			
• Appearance (fidelity)	----------	X	
• Navigation/Anchor Lights	----------	X	
• Hydrodynamic Performance	----------	X	
• Preprogrammed/Instructor Control	----------	----------	X
Navigation Aids:			
• Include All Necessary	----------	X	
• Appearance (e. g., lights)	----------	X	
• Effects of Currents	----------	----------	X
• Position Adjustment	----------	----------	X

Table 2 (Continued)

Visual Display Requirements (Continued)			
Environment:			
• Time of Day (24 hrs.)	X		
• Sun		X	
• Moon			X
• Visibility Effects (Adjustable/Dynamic)		X	
• Fog		X	
• Rain		X	
• Sleet/Snow			X
• Haze		X	
• Clouds			X
• Wind		X	
• Curved Earth			X
Water Surface:			
• Sea State		X	
• Wind Effects		X	
• Movement of the Ship		X	
• Depth of the channel (e. g. , sandbars)			X
• Surf Zone			X
Harbor Model:			
• Consistent with Chart	X		
• Tidal Change Indicators			X
Auditory Representation Requirements			
• Bell & Horn Buoys		X	
• Wind Noise		X	
• Bow Wave / Sea Noise		X	
• Automatic Contact Sounds			X
Communication Requirements			
Speech Recognition:			
• Speaker Independence	X		
• All Interior Communication Phrases		X	
• Harbor-Specific Terms			X
Speech Synthesis:			
• Autonomous Agents (Navigator, Helmsman,		X	
Contact Coordinator, Etc)		X	
• Correct Repeat-back Phrases			X
• Correct Timing of Repeat-backs			X
Sound System:			
• Completely Software-Based			X
Scenario Construction Requirements			
Initial Conditions		X	
Programming of Contacts		X	
Instructor/Operator Station Design			
Single Large Screen Display			X

SPAN Interface

The initial VESUB project plan called for linking VESUB with the existing Submarine Piloting and Navigation (SPAN) trainers to incorporate an OOD into this training process. SPAN, a proprietary training system developed by Evans and Sutherland (E&S) employs imaging and computing systems that are no longer readily available.

The interface plan was to drive the VESUB system with positional data and contact information provided by SPAN. This would allow the VESUB image generator to create the visual scene required to match SPAN images. Because the participants would not be viewing the same data, the models did not need to be identical, only similar. Own ship and contact positions, and geographic scenes, however, needed to be closely aligned, as the OOD would be making decisions based on these elements. Contact type and color could be matched during scenario construction, and other issues could be dealt with from within VESUB.

Hardware inspections of SPAN were conducted and maintenance connectors were identified that would provide VESUB access to SPAN system data. Consideration was also given to creating a Y-connector that would allow VESUB to tap-off of existing data transmission lines between the SPAN components. A data stream was tapped and SPAN data were recorded that potentially contained the appropriate information for creating a parallel simulation between VESUB and SPAN. No further action was taken on this aspect of the project because it was recognized that the costs of producing this hybrid system for the VESUB technology demonstration, beyond capturing the data, exceeded the available VESUB resources.

Simulation Requirements

Several key requirements were identified as necessary elements for a successful virtual environment. Many of these were fully developed. Some were only partially completed, while others were not developed at all.

Submarine Dynamics. Accurate simulation of the baseline model(s) is essential for the participants to accept that they are operating within a realistic virtual world. VESUB's two submarines demonstrated that multiple models could be built to support training requirements but the associated hydrodynamics were not fully and accurately implemented. This resulted in inaccurate reactions to passing contacts and those working along side, which translated to errors in pitch, roll, and heave. This indicated the need more accurate hydrodynamic interaction elements.

Modeling of a ship's progress through water, or the effects known as advance and transfer (see Figure 2), requires an understanding of how the fluid body effects this motion. The Hydro Module of the Virtual Ship application provided by AME accounts for this, either by providing the necessary computations that yield these effects, or by allowing specific ship-class data to be entered. To demonstrate the capability of the system to execute hydrodynamics effects, developers leveraged the existing surface ship models found in the Virtual Ship product and modified the turning characteristics and acceleration/deceleration rates to imitate the

performance of the two submarine classes included in the VESUB system. This resulted in an inconsistent performance model that lacked all the motion characteristics necessary to represent real motion through the water.

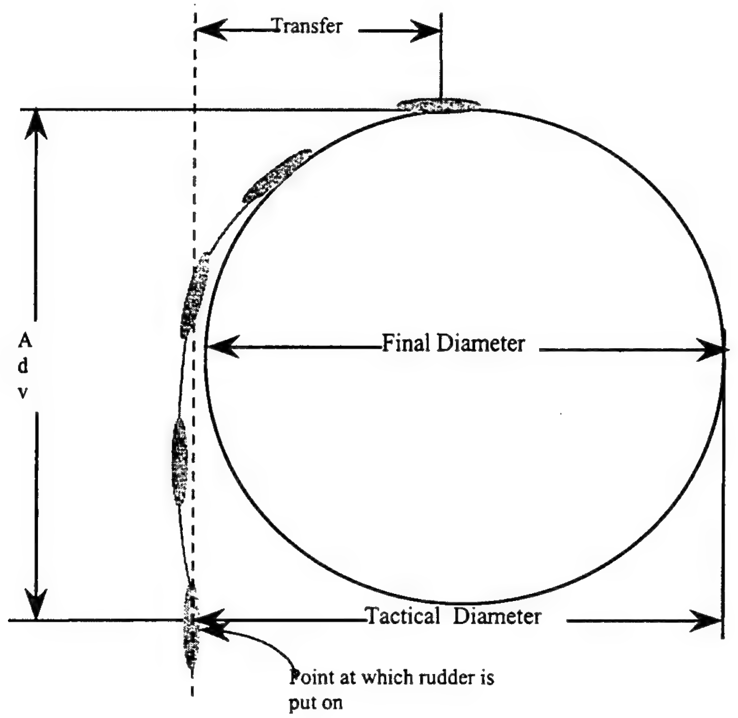

Figure 2. Advance and Transfer

Because ship maneuverability is one of the primary training issues being addressed, accurate representation of maneuvering is important to the successful employment of VE as a training delivery tool, both for VESUB and for other VE trainers. Speed orders for VESUB were received and displayed in standard navigation terms. These included engine orders bells for: All Ahead 1/3, 2/3, Standard, Full, and Flank and All Back 1/3, 2/3, Full, and Emergency. Speed orders can also be ordered incrementally in revolutions per minute as marked by the underwater log or by propeller shaft RPMs or "Turns."

Turns per knot, or TPK, is the ratio of shaft RPMs to 1 knot of ship's speed. A TPK of 5 would mean that 5 revolutions per minute would propel the ship forward at a speed of 1 nautical mile per hour. Ten RPMs would yield 2 knots, 15 RPMs providing 3 knots and so on. Because these values are often different for each ship class, and are key to precise shiphandling, it is important that the models be accurately represented. VESUB did not successfully implement this feature, specifically limiting a trainees ability to issue speed and engine orders in TPK increments. While impact on the TEE was minimal, failure to execute this feature in a shiphandling trainer will limit precise shiphandling capabilities.

Collision detection, the ability to determine when objects in the simulation make contact with each other, was considered a significant issue by the VESUB team. Early in the design phase,

sufficient evidence and emphasis were presented to the developer to support the need for this requirement. This feature holds the potential to enhance the immersion effects of the virtual environment by providing realistic cues that demonstrate the consequence of the trainee's actions. This feature was important for visible objects, but even more important to demonstrate the effect of contact with hidden objects (e.g., the channel bottom).

Effective collision detection must recognize objects that have mass and would impact the passage of the submarine. These objects, both on and in the water, include the channel bottom, piers, buoys, navigational aids, other vessels and waterborne debris. The developer considered this feature to be a difficult challenge because it would require the addition of a layer of instructions that would map and track object boundaries continuously to achieve the required detection. It would also require a wide range of detailed responses to collisions that would demonstrate the effects of impacting with other objects of various size and mass. This could range from a full grounding of the VESUB vessel, deflection and shuddering caused by the impact, sinking of other vessels, or damage to the object or own ship's control surfaces (rudder, stern planes, or screw). Though collision detection was identified as a key item in VESUB's functional requirements, it was not implemented. This critical feature needs to be developed for VESUB 2000 and future shiphandling training systems.

Currents. Understanding the impact of currents on your vessel and others, is a critical component of shiphandling. These conditions change continuously and differentially impact the task each time that an OOD maneuvers the ship. Harbor and channel current information was adequately modeled for the VESUB technology demonstration. A database was constructed that generated realistic values, based on historic tides and currents, for the harbors built for the VESUB project and the trainee's vessel responded appropriately to these programmed forces. These effects, however, failed to represent the environmental conditions fully because they were only applied to the ownship. Other vessels, buoys, and debris positioned within the scenario remained unaffected by the currents.

Detailed elements associated with currents and tides that needed to be modeled but were not are:

- tidal rips
- indicators of current strength
- scarring around piers
- canting of buoys
- swirling eddies at fixed objects
- indication of the rise and fall of tides
- shoaling indications associated with color, texture, and transparency of the water
- sand bars
- beaches
- grasses
- buoy location

Although VESUB dynamically simulated the changes associated with time of day, longer dynamic changes (e.g., diurnal/semi-diurnal, season of the year) were not implemented. These changes offer additional realism to the simulation as the trainee may be in the VE for an extended period.

Wind. The modeling of the wind effects, as identified by Tenney, et al. (1996) was not completed in VESUB. There are only minimal wind effects present in the VESUB visual scene. Some of the key indicators used by the OOD to determine the direction and force of the wind are; cloud movement, sea surface effects such as spray and white caps, swaying and blowing of fixed objects on shore (e.g., trees, bushes, flags), wind blown direction of the seas, ownship flag(s), and increased noise levels.

The physical effects of wind on ownship, contacts, buoys, and other objects were not sufficiently modeled to support the shiphandling task. The force generated by the simulated wind pushed ownship, but this was not proportional to the exposed surface area of the vessel, nor did it respond to the angle of impact. Similar to current, other objects in the scenario were left unaffected by the simulated forces of the wind. The trainee was left to deal with wind that set his vessel left or right of track, but had no indicators (e.g., moving clouds, waving flags, surface spray, canting of passing sailboats) to support his decision process. In addition, he may have falsely anticipated the track of other vessels operating without the effects of wind.

Visual Display Requirements

System developers need to understand that each enhancement added to the visual display exacts some price. Whether against a budget line, in delayed refresh rate or computational resource, there will be an impact that will need to be planned and accounted for. Nevertheless, the following visual requirements justify additional development to support the requirements of the task.

Own Ship/Topside Areas. There are two key concerns about the manner in which VESUB represented the submarine's bow. The first is related to the visible shape of the bow, while the second has to do with how the bow shape affected the ship's motion through the water. A submarine's bow is broad, round and bulbous. From above the water much of the bow is concealed. The greatest portion of it being below the water line. The waterline provides a smooth, concentric arch across the front of the visible structure. The VESUB model portrayed the waterline as a series of straight lines linked as parts of an octagon, which was unrealistic and distracting to the trainee.

Due to this design, the bow of the submarine slips through the ocean unlike any other vessel. The rounded hull displaces the water and causes it to build a wave that moves over and around the submarine as it thrusts forward. This action forces the bow down, not up, and in general the submarine does not ride the waves as a conventional surface vessel would. The submarine hydrodynamics models was leveraged from a surface ship model with its traditional bow actions, which inaccurately represented rise and fall of the bow in the visual scene. Creating a rounded bow and employing accurate submarine hydrodynamics are needed to improve the accuracy of

the visual scene and to provide the correct visual cues (e.g., shape and location of the bow wake) to the OOD as he experiences the shiphandling task.

Because the VESUB submarine hull model was not accurate, the bow wave presentation resulted in a less robust representation of the wave than is produced by either the 688I or 726 class of submarine. In reality, the bow wave and trough generated by the submarine hullform starts just aft of the bow at slow speed. As speed increases, the wave front and trough move aft, drawing deeply against the hull. The wave, with its froth and foam, has two distinct parts that needed to be represented in the VESUB model. First, a deep wave angles out as a broad V that moves sharply (45 degrees) away from the ship. This is a wave-swell (not white water) that is pronounced and distinct at speeds greater than 8 knots. White water generates, as the second part, from the breaking water of the bow and the related suction effects that are at work. This broad white wave begins at the point of break, located between the bow and the sail, moving aft and extending out from this point with point-of-origin and force as a function of speed. The modeling of these effects needs to be improved to properly provide speed and sea state cues to VESUB trainees.

The size of the wake generated by the submarine is a function of the bow wave and the propeller generated scar, both create white water and chop that persist for an extended period of time and distance astern of the submarine. The wake begins to spread out from the ship starting at the point of bow-wave break between the bow and the sail. It becomes wide and pronounced at speeds above 8 knots. At "All Ahead Standard," its width is more than three times that of the ship, or 50+ yards wide, extending aft to combine with the stern wake where it persists for several miles behind the ship.

The propulsion component of the submarine's wake, or stern wake, starts at the propeller. At slow speeds, it churns water just aft of the rudder, and starts to add white water to the bow wave. At speeds above 3 knots, it is pronounced and persists for several hundred yards astern. At high speeds, it places a long, wide trail astern that is a useable tool to the OOD because it shows his path and course maneuvers. Wake activity can also indicate sea state and current information that the OOD can employ as he maneuvers the ship.

Functionally, engine order bells, in either direction, should create a churn at the rudder. Backing bells will force white water to wash up and over the engine room hull forward of the rudder. The higher the engine order bell the more churn created.

Lights and lighting effects provided in the visual system were, in general, less than satisfactory because light size and reflective features were either not present or inaccurately represented. Shipboard lights, such as the submarine identification beacon, port and starboard navigation lights, anchor light, stern light and bridge spotlight were not effectively modeled in the VESUB system. Though shipboard lighting is predominantly intended to provide location and recognition markers for other vessels underway, it also provides cues to the OOD related to the shiphandling task. For example, viewing the stern light's 'loom" allows him to judge sea state. Other lighting issues, on hull and off, include the effect of glare and reflection, as well as, the lack of shadow and texture. The submarine ID beacon, for example, strobes the bridge area and reduces the OOD's ability to see other features in the scene. This light was not modeled in

the VESUB, however, it is necessary to provide a realistic level of interference for training night operations.

Effective implementation of lighting effects requires a significant increase in polygon construction, because the illumination and shading within the scene must be created by filters and masks placed over the modeled objects as they come within range of the light. It is recommended that this level of detail be incorporated into the operational VE trainers that will represent night operations as a part of their training environment.

While the representation of masts and antennas was satisfactory for the VESUB technology demonstration, these items lacked detail. Because these items are all located close to the OOD's position in the VE, their fidelity should be increased to improve the trainee's sense of immersion. Areas of concern for masts and antennas included accuracy of diameter and height, geometric shapes (cylindrical rather than octagonal), detailed fittings for optical windows and the like, as well as functional designs for specific masts such as, ESM and snorkel mast heads. In addition, these objects must accurately obstruct the trainee's view whenever placed in the field of view (FOV), and this includes during the use of binoculars.

Bridge Area. Provision of additional details associated with the submarine's bridge would enhance the immersion effect. The bridge suitcase is the only instrumentation provided to the OOD on the bridge of the submarine. The modeling of the VESUB bridge suitcase was effective and met most of the functional requirements. However, it also acts as a communications center, with a combined speaker and microphone system and several circuit selector switches and a collision alarm button. The complexity of the interface necessary to select these switches prevented the development of this option. Switch selection could be a reasonable candidate for limited haptics application and should be considered as a means for accomplishing these types of operations within the VE.

The VESUB compass adequately represented the shipboard display, but lacked the ability to sight along the "Alidade," to mark bearing data to vessels, geographic or cultural features, and navaids. Because the OOD has few tools at his disposal, it is important that as many as possible be provided for his use. Inclusion of this function was considered, but a ready interface was lacking. Voice and haptics interfaces options were considered. However, development was outside of the scope of the VESUB technology demonstration. The alidade was not determined to be an effective tool for use within a VE. Consideration must be given to the limited motion given the constraints of the simulated environment for safety reasons and potential damage to the HMD.

VESUB incorporated a dynamic chart representation into the bridge design. Charts were scanned and resized for use in the VE. As the scenario progressed, the chart automatically changed to provide the OOD with the correct chart for his position along the track. The charts were prepared using standard practices that would be common to shipboard chart work. Additionally, clutter that may have slowed image processing and confused readability was removed from these images.

While the VESUB TEE participants liked the charts and felt they were solid representations of those that would be available for use, they also felt that the opportunity existed for the system to support training by placing a dynamic positional marker on the ship's position. This was considered a useful tool that might be engaged in support of the training task.

The VESUB harbor databases included two standard submarine ports. Because each ship is responsible for preparing its own charts, the VESUB team considered methods that would have allowed the participants to use their own charts during training scenarios. The use of NIMA provided digital charts for direct loading was also considered. The implementation of these features, while outside of the scope of the VESUB project, are considered excellent extensions of the charting capability and are recommended for inclusion in follow on systems. The ability to incorporate the real shipboard charts would allow trainees to exercise real world skills within the VE, while direct downloading of digital charting would support the development of additional harbors and might support mission rehearsal.

A simplified maneuvering board was considered for inclusion in the visual scene. Though considered a valuable feature, the maneuvering board was eliminated from the list of options due to budget constraints. A maneuvering board and supporting voice recognition requirements should be incorporated into any future VESUB system design. This tool, as suggested by several SMEs during VESUB development, could be designed into the windscreen display, fashioned after the rough contact geometry's often drawn by the OOD's. An automated posting of data could be incorporated into any of these designs to provide the trainee with the necessary information to support contact management.

The TEE participants made several suggestions for tools that might reasonably be included in future systems. Consideration should be given to the development of haptically-driven tools, potentially with force feedback, to allow for the use of:

- Virtual pen to allow log and computational entries
- Virtual flashlight
- Virtual spotlight
- Virtual microphone
- Other virtual communications devices, such as phones or hand sets
- The ability to see a virtual body representation, with torso, hands and feet in the scene
- Visually simulated hands to allow the trainee to point with reasonable accuracy

Contacts. The visual modeling of the contacts in the VESUB technology demonstration was satisfactory. It is believed that improved detail would support immersion and should be considered in the development of any VE system. Higher fidelity of the virtual scene should improve shiphandling training because it supplies the cues necessary to allow the OOD to evaluate and execute his task. He gains speed information from a contact's bow and stern wave activity, evaluates range based on deck and mast heights, and determines angle on the bow (AOB) based on contrast and depth perception. Higher fidelity models provide these elements, and more, where lower quality rendering eliminates these cues, and with them the OOD's ability to make accurate judgments.

Vessels, even small ones (at short range), usually stand out in real world situations, but they often blended into the virtual scene causing missed classifications and inaccurate analysis of range, course and anticipated actions. Improved graphical representation would reduce this conflict. Much more emphasis is needed in accurately modeling these features for all objects.

The appearance of a contact's lights can impact the OOD's ability to perform in night time scenarios. Specific contact lighting problems included:

- placement of lights off-hull instead of on the contact
- lack of surface illumination from light sources on contacts
- lack of accurate directional effects from contact navigational lights
- inability of the system to resize lights as contacts closed or opened range

Modeling of vessels needs to accurately account for deck and cabin lights as well as working lights and those in companionways and passages. Ships don't generally operate in a state of "darkened ship" and these realities need to be properly represented in the VE to provide realistic visual cues that support the task.

One of the most significant contact issues was inaccurate hydrodynamic modeling. Contacts operated without being affected by wind, currents, other contact wake effects, and were unconstrained by geography. While there may not be a need to fully model the specific hydrodynamics of each contact, there should be, as a minimum, standardized rules of hydrodynamic interaction for each contact to ensure effective shiphandling presentation.

Contacts also need to be controllable by the instructor while the scenario is running because the interactive nature of the VE task prevents the instructor from anticipating trainee actions ahead of time. This capability was limited in the VESUB system, but needs to be improved in future trainers.

Navigation Aids. The VESUB project developed two harbor databases that were based on the current charts and navigation information for those locations. Navigational aids (navaids) were identified by team SMEs. Several of the identified cultural features and navaids were omitted. Careful evaluation and consideration must be given to all available information.

The "Navigational Ranges" offer the best example of placement errors. These key channel markers are fixed placards that provide an alignment stripe as a reference to channel center. They are often hundreds of yards apart, and can be seen several miles away. Minor errors in placement on the part of the developers resulted in tens of yards of navigational error. The primary cause of navaid placement errors was the design of the coordinate system within the database. While these errors appeared negligible to the developers, they were actually quite large relative to the navigable water, some representing more than 20% of the width of the channel. Ultimately these errors necessitated redevelopment of VESUB's coordinate system. In addition to the requirement for exact object placement, the ability to add, delete, and move objects easily is recommended for future shiphandling simulations.

The visibility of navaids due to contrast, shadows, and textures plays a significant role in the shiphandling task. Of particular importance is the identification of navigational aids and vessels at reasonable distances. The background colors and textures used in the VESUB visual scene lacked contrast and dimension. They sometimes blended unrealistically with other modeled objects within the scene (e.g., range markers blending into the trees behind them). The trainee's inability to see range markers, navigational aids, and geographic features made the task unrealistically complex.

The size of navaids, especially buoys, also proved to be a problem. The environmental software development package didn't properly account for distance and was also constrained by pixel placement at extreme range, causing size to change disproportionally to the distance to the object. Channel buoys were the worst offenders, growing to large towers within the scene depending on where the VESUB vessel was positioned and often dwarfing traffic vessels passing them in the channel.

Lights on the navaids demonstrated the same problems noted previously for lights on vessels, most notably lights at a distance were easier to spot than at closer ranges because they retained their 4-pixel size regardless of distance. The illuminating effect of lights modeled within the VE normally had no physical shape or range related luminescence and subsequently appeared the same, regardless of the viewer's distance from the light. While this could have been accounted for by modeling improved visuals there would have been a sizable increase in polygon rendering to meet this need. If training systems are going to support nighttime simulations this problem will need to be solved.

Unlike stationary navaids, buoys move with the tides and currents varying as a function of the direction and force of the seas and the length of their chain. This is a noticeable feature that OOD's of all ship types use to evaluate their environment. Buoy set and tending is well defined as the buoy leans against the pull of the chain and produces a swirl or eddy at its base. Though a key shiphandling indicator, this feature was not developed and needs to be incorporated for future systems.

All objects, stationary or not, are subject to wind and storm damage and are sometimes lost or drift out of position (buoys) and become unusable to the OOD. The instructor/operator should have the ability to remove or reposition buoys within the database to exercise this aspect of shiphandling, and to allow buoy modification and insertion of additional navigational aids to the database.

Training systems are often developed with a software design freeze on improvements due to a lack of time or resources. The ability to easily update systems is critical to the life span and usability of the system to support real-world environments of the future. The ability to modify the navigational databases for shiphandling training systems would allow trainee's to experience real-world conditions that they can relate to versus a static version developed years in the past. The ability to modify these databases supports transfer of knowledge and experience and as such, provides a significant training benefit. This capability was not incorporated into the VESUB technology demonstration system, but needs to be included in future shiphandling training systems.

Environment. VESUB's marine visual effects were created using Vega Marine software from Paradigm Simulation, Inc. It was selected because it was considered the best marine effects product available in the market for use on the SGI Onyx platform. As evolving software, its capabilities have improved significantly and many of the issues relative to visual scene effects in VESUB have been improved. Some issues, however remain significant to the development of VE systems. While time of day was functional, nighttime events were less than effective due to the lack of ambient light effects from the moon and land based sources, as well as, from vessels and navaids. Daylight was well modeled, but the sun was not part of the visual scene and reflective glare and shadow effects were not present. Additional improvements to the surf-zone, waves, background lights, light points, and environmental features.

The modeling of precipitation was incomplete. For example, the only indication of a storm was the sound of thunder and a general darkening of the sky. Weather fronts, such as cloud masses, fog, driving rain squalls were not programmed as moving objects nor had any association with movement induced by the wind. While the instructor operator could adjust the visibility range during the scenario, this activity drew him away from monitoring trainee performance and would be more effective if automated.

Of all of the environmental issues that need to be addressed, especially for a marine simulation, Earth's curvature is the most significant. As ships approach land, or other vessels in open ocean, they begin to see the tops of mountains and masts of ships from afar. This is because the body is obscured by the curvature of the Earth. In the modeling and simulation arena, this aspect has been overlooked because most of these training environments have focused on aviation based tasks, which are easily supported with flat earth projections, due to the impact of altitude and speed. Earth's curvature impacts the view of ships and objects on the horizon. (see Figure 3) As the observer's height of eye, or viewing point, is close to the Earth's surface, modeling within this scene therefore, must include the ability to see objects appear or disappear over the visual horizon. The surfaced shiphandling task provides a limited angular perspective that calls for either a curved earth model or a modified surface view in which objects are adjusted in a height/distance relationship as they approach or subsequently retreat from view. This requirement may eventually drive effective geographic modeling for simulation and VE applications, but due to its technically difficult nature, it was not available for use within VESUB.

Figure 3. Earth's Curvature Impacts View of Ships or Beyond the Horizon

Water Surfaces. VESUB's marine visual effects provided a reasonable representation of the water surfaces and met the needs of the technology demonstration. The nature of the programming for both hull models and water surface, however, did not allow for an accurate representation of wave action at higher sea states. Choppy seas and white caps had an artificial look that detracted from the scene. More accurate sea state and tidal/current indicators, such as the representation of eddies and tide rips also require significant improvements. Additional "Seaman's Eye" elements that would support the shiphandling task include bottom swirls that indicate ship's movement in shallows and the creation of rip tides and surf zones, especially near large obstructions such as, submerged structures and points, promontories and rocks. As surf zone and shallows are being better represented in recent revisions to these software tools, so too may tidal change indicators be improved to mark rise and fall on cultural features, such as piers and jetties.

Auditory Representation Requirements

The use of sound within the VE enhances the trainee's immersion. The use of stereophonic sound, supported by two channel audio input to the HMD, further provides an audio component that reflects reality. The use of audio cues in VESUB was an issue from the project's beginning. By leveraging the audio components used for the voice interface, along with Audio Works software, a small series of environmental cues were implemented. The two mixing panels used to control the audio paths and amplification were set up to feed both the trainee in the HMD, and the instructor's console speakers.

It is believed that greater realism and increased immersion will result in improved training with significantly less distractions. The VESUB team did not fully develop a plan to support environmental sounds for the technology demonstration. However, the audio cues that were employed appear to have significantly enhanced the immersion effect of the training. The hardware and software tools employed by VESUB allowed the developers to introduce audio sources such as, wave and sea wash, wind (increasing wind with ship's speed), bells and whistles from buoys, and contact whistle signals into the environment. Although the generated sounds were not truly spatial, these cues prompted the trainee to look and act in response to these stimuli as they would in the real world. The need for further development of this capability is considered essential to achieving the maximum training impact available to a virtual system. Other sounds typical of harbor navigation and shiphandling that will enhance realism and should be included.

Examples of harbor sounds include:

- Horns
- Whistles
- Bells
- Fog horns
- Dynamic traffic

Mechanical shipboard noises, such as, the sound of exhaust blowers and diesels, communications circuit transmissions, wind and sea noises (e.g., increasing noise from the own ship's bow wave), and associated noises from tugs and traffic that operates or passes within reasonable range of own ship. These features all need to be spatially implemented to provide realistic scene accuracy.

Safety is a paramount concern in the development of training simulators. The experience gained through the VESUB TEEs demonstrated that dangerous volume levels could be sent to the HMD and for this reason it is important that these system-generated sound effects be controllable from the IOS. A software package is needed to implement audio controls that can provide operational safety features to protect VE participants.

Communications Requirements

Speech Recognition. The VESUB system employed a speaker independent voice recognition system with a supporting synthesized voice response. Subjects operated the system using a press-to-talk microphone interface, the system responded appropriately and synthesized speech was generated and output to the trainee via head phones in the HMD and speakers at the IOS, for instructor monitoring.

BBN's voice system, "HARK," proved effective in this role accommodating variations in volume, pitch, and tone with good functionality, and even allowed participants with heavy accents to successfully operate VESUB. In general, the accuracy of speech recognition was above 90% for correctly phrased commands and inquiries. The VESUB team believes that 90% is not high enough to support the normal maneuvering watch environment that trainees will typically experience in the real world. Software filters could improve this rate, but adjustments to these sensitivity levels will modify the ability of the system to understand all trainee voices.

Trainee speech patterns, such as, delays and pauses, higher pitch, fast or slow speech, and excessive volume, accounted for most of the recognition problems. Alternatives to the current process might be adjustments to the time allocated before the system begins phrase parsing; the ability to suspend parsing and recommence this operation if a continued transmission is received; linking the parsing process to the open microphone, commencing it automatically on switch release.

Operation of the microphone button caused interference that was interpreted as a command, causing the system to begin the process of analysis. The end result was the generation of an erroneous command or a "say again sir" response. Mechanical noises, such as, switch clicks and electronic feedback, should be filtered and eliminated from the recognition process. The use of software controls for input and output volume will improve the ability of the instructor to factor this out of a given exercise or for a specific student.

Several voice related system errors occurred which locked up the software modules or generated cascading synthesized responses. This cascade of responses (often four or more) monopolized the system and prevented the OOD from acting to correct the confusion. At other

times, when the system was unable to identify the received command it became confounded and locked up. While these problems were easily accounted for in the technology demonstration they will not be acceptable in an operational system and need to be corrected.

Several key phrases and words were omitted from the library database, among these are harbor specific terms, navigational aids, geographic and cultural features, and some standard navigational terms and technical phrases that OOD's will employ in their speech. Examples of these omissions are: Chesapeake Light, Cape Henry, Fort Clinch, and cardinal headings phrased as "course north, south, east or west." A detailed listing of possible phraseology is required to support shiphandling training. Development of a more intelligent voice synthesis system would greatly improve voice recognition technology and the ability to simulate autonomous agents.

Speech Synthesis. The VESUB speech synthesis used recorded voice to generate responses and to make system initiated reports. This represented an improvement over computer generated voice available at the time of software selection, but advancing technology may make the use of synthetic voice advantageous over recorded speech, especially when it comes to the ability to modify response vocabulary.

The recorded speech used in the voice response system employed by VESUB proved to be too slow to properly represent response time of stations subordinate to the OOD. Timing in these communications is critical. The Helm, for example, would not delay his repeat back to an order until after he had accomplished the task. He would act on the command and repeat it back at the same time. The rudder would be coming over to accomplish the course change as the Helmsman responded to the OOD. The reason for this is that the ship is moving down track at a rate of 100 or more yards a minute and significant delays in time to respond would result in unacceptable ship's placement. Response timing must be improved to effectively represent a highly efficient maneuvering watch team supporting the OOD.

The OOD, observing the environment as he pilots the submarine, generates orders based on his observations, and adjusts these orders to fine tune his position in the channel. When the OOD is ready to give an order, such as in response to a Navigator's marked turn, he must be clear to transmit his command. He may delay for a single helm report, but he can not be held at bay while a series of reports are transmitted from the voice buffer. It is important that the OOD be able to realistically break into the communications net when needed. Additionally, key Navigator reports, like "marking of turns," should take priority over other reports to allow the OOD to act on the track recommendation. The system must accommodate these communications elements.

VESUB system configuration prevented the receipt of new OOD orders or inquiries (recognition) while the voice response system was transmitting (synthesis). This process needs to be corrected so that this conflict does not exist in future systems. Voice operations should, however, be constrained to match the real 7MC-circuit transmission priority.

As the OOD dynamically issues his orders the virtual crewmembers should change both actions and reports so that responses are in consonance with the OOD's requirements. This parallel set of actions should also drive modifications to voice responses that are in the buffer's

que. A new ordered course, rudder order, or engine order should override any action and report that is pending, as a real Helmsman would not act on and report an element that has been overridden by changing status, events, or orders. As an example, an All-Stop that is modified to an All-Back 2/3 should not be acted on and reported, as the All-Back 2/3 takes precedence in the order that it was given. Ultimately, some ability for the system to prioritize actions and reports must be considered in the programming of technologically advanced virtual training systems. Simple word/phrase response structures will not suffice.

The synthesis process is also part of the response cascade issue, in that this side of the system acts on the direction of the recognition process, and it may be able to be addressed from the synthesis side of the software. The solution may be to limit the number of responses (literally) that can be selected for a single order. More review of this issue is needed.

Sound System. The VESUB sound system was a hardware add-on to the SGI INDY desktop computer. It worked in conjunction with the audio effects provided by the Audioworks software package and was suitable for the technology demonstration. However, this system is not well suited for a primary trainer because it required a host of cables and several adjustable components to remain unprotected in the open. This design incorporated audio channel volume control slide bars, which were easily knocked off their intended levels. A solution for this problem is a software controller (like those found on many CD players in personal computers) to provide adjustments to audio output levels, filtering and balance.

Scenario Construction Requirements

VESUB's scenario construction capability was based AME's Virtual Ship software. These applications located several layers deep in the VESUB architecture, provided the necessary tools for scenario construction and modification. The development of training scenarios dictates that the instructor/operator design a problem around learning objectives that focus on specific events and key tasks that the trainee must master. Developing scenarios and managing them during training was a key feature proposed for the VESUB project. This functionality was intended to allow the trainee to enter into a training session that would begin with a reasonable set of circumstances and evolve as a function of the trainee's actions. This process must be a complex and dynamic one that automatically adjusts the simulated scenario events to match trainee driven interactions, and one that allows the instructor to modify the scenario in real time to meet these needs.

Setting Initial Conditions with the Scenario Development Interface (SDI). VESUB had several modules that had to be mastered by the operator before he could effectively produce scenarios. The SDI, included screens to initially develop and modify scenarios; set initial conditions for ownship; establish the basic operating variables for the simulation; and an interface to set, control, and modify traffic vessels. These elements are independently developed and then linked together for each scenario. Initial conditions could either be selected by recalling previously constructed scenarios, or by initiating construction of a new scenario. This allowed the operator to save development time by leveraging established scenarios or to build an entirely new scenario to meet training objectives.

While the VESUB scenario development process proved acceptable for use in the technology demonstration, its complex nature was difficult for most operators. A simplified design is necessary to support effective scenario development. The solution may rest in either a more functional graphical user interface (GUI) or pull-down menu design.

Programming of Contacts. Contact performance was of concern to the operator, whose task was to try to optimize system capability during scenario development. The operator's tools must allow him to accurately place objects into the exercise area, and he must be reasonably assured that they will do what he expects once they are entered. Contact placement, operating characteristics (hydrodynamics), and time driven commands (waypoints) must be dependable and, when running, must execute as expected.

Though the VESUB operator who developed scenarios was able to effectively overcome many of these issues, the scenario development process was never refined to the point desired. Contact placement and management remained a problem throughout the project. While the expertise of the primary operator allowed effective scenario development, the average operator would have been much less successful.

Instructor/Operator Station Design Issues

The IOS implemented for VESUB was leveraged from AME's Virtual Ship product, which supported surface shiphandling training. AME's initial IOS design for VESUB varied only slightly from their baseline device. System operation through this IOS was functional, however, it was neither intuitive nor submarine oriented. Terms and images that appeared on the IOS reflected its surface ship background, and many of these had no submarine application.

Ease of operation was considered essential by the team because the instructors running VESUB were not, and would not be, experts on the system. IOS design and usability was the focus of a system analysis reported in Hays, et al. (1997) which provided additional details on the functionality and design features of the VESUB IOS. The goal of the team was to have an IOS that would allow ease of system operation for all assigned instructors, and that would effectively support scenario management throughout the training cycle. In the end, the IOS design was a compromise between the desired functionality and operability and the limitations imposed by time and financial constraints. The team had intended to move to a single large-screen display for all IOS functions, driven by pull down menus and screen-in-screen projections. Instead the VESUB IOS remained on two mid-size screens requiring the operator to shift from one to the other to manage training events.

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CONCLUSIONS AND RECOMMENDATIONS

The VESUB R&D technology demonstration system integrated and fielded a content rich training system, capable of effectively training a complex task for trainees with varied skill levels. The results of the TEE, one of the first conducted for a virtual environment trainer, and the lessons learned throughout the VESUB development process point to several important conclusions and recommendations:

- VESUB provides effective shiphandling training
- Team communications is a must in the development of complex systems
- Legacy based system development must be closely evaluated
- Configuration Management is essential for success
- Complex scenes require sufficient fidelity to support training requirements
- VE offers unique presentation capabilities that should be exploited

VESUB PROVIDES EFFECTIVE SHIPHANDLING TRAINING

Data from the TEE on eleven of fifteen variables showed significant learning in a variety of shiphandling skill areas. It can be said with confidence that VESUB technologies can provide effective training. However, a training system is far more than just technologies. It can not be stated too strongly that a training system will only be effective if it is used correctly. Care must be taken to implement the technologies in VESUB in a manner that is consistent with known learning principles.

TEAM COMMUNICATIONS IS A MUST IN THE DEVELOPMENT OF COMPLEX SYSTEMS

To effectively manage a technically complex and content specific project, the lines of communication must be established at the start of the project and maintained throughout. This is often a difficult task, even when the entire team is located within the same lab or office, and it is made more difficult when the team members are spread out over several sites. Creating a team communications plan including communications paths, delivery plans, information flow and routine project meetings is essential to the success of the team process. Implementation of this plan allows members to effectively interact to share vital information before incorrect decisions are made. Failing to formalize this process can result in lost data, team conflict, false starts, and ultimately result in project delays that stem from these issues.

LEGACY BASED SYSTEM DEVELOPMENT MUST BE CLOSELY EVALUATED

While saving project resources is an attractive motivator, employment of a legacy system as the basis for a new system may not be the best solution for long-term development. The system developer for VESUB was selected because they had a strong background in maritime

simulation, especially in harbor navigation and piloting. It appeared a simple task to convert the Virtual Ship software into a Virtual Submarine, but this conversion proved more difficult than expected. The programmers focused on keeping the structural integrity of the base system and opposed changes that would have made it more suitable to the submarine domain.

Additionally, there should be a concern for the continued use of legacy systems that are not evolving with technology. The VESUB architecture employed a layered design that integrated software packages, one atop another, in a complex design. Driven by the legacy structure, VESUB employed the same software tools that had proven effective for Virtual Ship, without consideration for new tools that had been developed in the interim.

CONFIGURATION MANAGEMENT IS ESSENTIAL FOR SUCCESS

VESUB hardware and software development was accomplished at AME's primary site in Arlington, VA. Revisions to the software were transferred electronically, to the NAWCTSD VESUB lab for incorporation into the system. Several differences were noted between the performance of these two systems, and delays were experienced based on these differences. These problems were isolated to systems configuration variances between the two sites, and work-arounds were built to overcome each problem. Systems efficiency could have been improved, however, had strict configuration management procedures been employed. It is recommended that projects establish and adhere to a specific hardware and software configuration plan. When multiple sites are used for developing and testing systems, hardware suites must be duplicated exactly to ensure configuration and operating consistency. Software applications employed will also need to be controlled, ensuring that titles and revisions are identical and that any bridges, jumpers or patches installed at one site are also installed at the other sites. This problem may not be completely overcome through configuration management procedures, as many high-end computer systems are unique and will not be identical even when carrying the same model name and number, but it will be greatly reduced through this strategy.

COMPLEX SCENES REQUIRE SUFFICIENT FIDELITY SUPPORT TRAINING REQUIREMENTS

Development of an image rich environment for a VE based training system requires that the developers achieve an understanding of the visual scene being managed and that they have an appreciation for the level of fidelity needed to engage the trainee in the virtual world. While full photo-realism is clearly not called for, there must be sufficient attention to detail so that the trainee focuses on the training tasks presented and not on the nature of the scene being viewed. Textures, resolution, and contrast between objects in the scene provide critical cues that allow the training subject to operate in VE without raising questions as to what he has seen. Examples of conflicting image elements include: 1) navigational aids that are not properly proportioned; 2) unrealistic or conflicting textures, such as background vegetation and navigational range markers (red and white markers blending with brown and green vegetation); 3) lack of contrast between objects or surfaces, such as small boats and the water's surface; and 4) as well as a lack of light, shade and shadow within the scene. Developers and modelers need to pay attention to these

details as they build the scene so that their negative impact is minimized, and the trainee sees the cues that he or she needs to succeed in the training task.

State-of-the-art image generators provide the capability to run multiple channels from the same database. Each of these channels can be assigned a unique viewing perspective (e.g., OOD, Lookout, periscope view). The same database that provides the visuals also provides a geo-situational screen (bird's eye view) that can also be used to drive other displays (e.g., radar, etc). It is strongly recommended that future systems, such as NAWCTSD's VESUB-2000 and SPAN-2000, fully exploit this multichannel capability, and that distributed systems or networked systems that share scenarios employ a common image generator and positional database, rather than attempting to synchronize two or more hardware platforms to meet these needs.

VE OFFERS UNIQUE PRESENTATION CAPABILITIES THAT SHOULD BE EXPLOITED

The unique nature of VE allows the developers and the instructional specialists to use new instructional approaches. As an example of this, VESUB has the potential for the OOD to shift his eye position from one point on his submarine to another, even from his vessel to another. This feature could transport the trainee to the other ship so that he would gain a more complete perspective of the navigational problem and better understand the impact of his actions on approaching contacts.

Limited only by imagination, VE will allow training systems to demonstrate complicated theory and technical specifics to better meet training objectives in an interesting and innovative way. Properly employed, these instructional capabilities may prove to be the most important aspect of the use of virtual representations in the training field.

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APPENDIX A

VESUB Hardware and Software

HARDWARE
Main Computer System: Silicon Graphics Onyx Deskside • Four R10,000 CPUs • 256 Mbytes RAM • One Infinite Reality Graphics Pipe with Two Raster Manager Boards (16 MB Texture Memory) • Scene Refresh Rate at 30 Hz • Capable of Displaying Approximately 21,000 Polygons (fully Z-buffered and anti-aliased)
Instructor/Operator Station (IOS): • Two Silicon Graphics INDY Desktop Computers
Head Mounted Display (HMD): n-Vision Datavisor HiRes • Resolution: 1280 x 1024 pixels • Field of View: 40 degrees horizontal and 30 degrees vertical (capable of stereo-optics for up to 70 degrees horizontal view)
Head Tracker: Polhemus 3 space Fastrack (Magnetic)
Printer: Epson Stylus 800, color Inkjet
Sound System: • Two Radio Shack SSM60 Stereo Sound Mixers • Two Rane MS1 Microphone Amplifiers • Two Radio Shack Dynamic CB Microphones, P/N 21-1172 • Two Radio Shack Speakers, Cat. No. : 40-1324

SOFTWARE
Visual Scene: • Models and Terrain Created Using ModelGen2 from Multigen, Inc. • Real-time, Interactive 3-D Scene Generation Controlled by SGI's IRIS Performer • Marine Visual Effects Created Using Vega Marine from Paradigm Simulation, Inc.
Instructor/Operator Station (IOS) Interface: • IOS Screens Created Using Visual Applications Builder (VAPS) from Virtual Prototypes, Inc. • Windows in SIMGEN and Start-up Screens Created with X-Designer Release 4. 5 from Imperial Software Technology Limited and Data Views Corporation
Voice Recognition and Synthesis: • HARK, developed by Bolt, Baranek & Newman, Inc. Implemented by UFA, Inc.
Audio Effects: •. Audioworks from Paradigm Simulation, Inc.

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